Nanostructures Made by Focusing Atoms with Laser Light

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Using the forces produced by laser light on chromium atoms, researchers at the National Institute of Standards and Technology (NIST) have deposited permanent nanostructures on a surface, in a process that could lead to a new way of making extremely small devices.[1] The near-resonant laser light, which is in the form of a standing wave grazing across the surface of a silicon wafer, acts as an array of lenses for the atoms, concentrating them into the nodes, or zero-intensity regions, of the standing-wave laser field. The structures consist of an array of extremely regular lines, one for each standing wave node. The line width is 65 nm--about 1/1000th the diameter of a human hair, and roughly ten times smaller than the smallest feature on today's microchips. While this line width is small, calculations predict that even smaller widths, as small as 10 nm or less, could be reached with refinement of the technique.

The manipulation of atoms by laser light has seen a dramatic increase in activity over the past decade or so, since the first demonstrations of laser cooling[2] and laser focusing[3] in 1978. From this pioneering research, the field of "atom optics", in which optical elements such as lenses, mirrors and beamsplitters for neutral atoms are made, has grown into a fascinating new area of atomic and molecular physics.[4]

Application of atom optics to the fabrication of nanostructures was first demonstrated by Timp et al. at AT&T Bell Laboratories.[5] In that work, sodium atoms were focused in a laser standing wave, depositing a periodic structure on a silicon surface in vacuum. Investigating the structure by observing the diffraction of laser light, Timp et al. were able to verify its periodicity and infer some information about its quality.

Until the introduction of chromium by the NIST group, however, the application of laser focusing to fabrication of nanostructures was faced with some difficulties. Structures made of alkali atoms (the favorite for laser manipulation work) are difficult to study because alkalis are reactive and tend to diffuse on a surface. For the first time, with chromium, deposited structures could be removed from vacuum and observed using techniques such as atomic force microscopy or electron microscopy. This development has opened the door to an array of in-depth studies, which are necessary for the application of this new technique to actual device fabrication.

Crucial areas of future research involve extending the process to include a variety of materials, and establishing the ability to make more general patterns. Other materials can be made accessible either through learning to laser-focus other atoms, or by using chromium as an etch resist, to which it is ideally suited. More complicated patterns can be approached by starting with a two-dimensional pattern of dots, made by using two standing waves perpendicular to each other, and scanning the substrate two-dimensionally within the unit cell of the standing wave. Even more general patterns might be created by using customized interference patterns on the surface.

At present, it appears that prospects are good for being able to make use of the inherent advantages of this laser focusing process, i.e. massive parallelism coupled with extremely high resolution, in fabricating novel and useful nano-devices. In the future, we can expect to see a wide variety of related processes emerging.

References

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Figure Caption

Composite image of chromium nano-lines deposited by laser focused deposition. Foreground: close-up atomic force microscope (AFM) image; background: large scale AFM image, showing uniformity of lines. The lines are spaced at exactly half the laser wavelength, or 212.78 nm, and have a width of 65 nm. Their height is about 30 nm.